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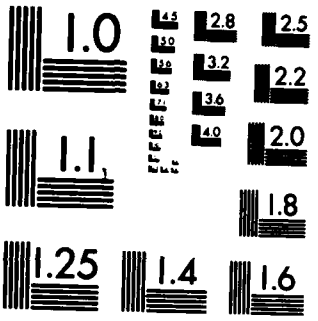

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by

Wang Gengchen

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ATTENUATION OF RADIATION IN THE 8-13 MICRON WINDOW REGION BY ATMOSPHERIC AEROSOLS

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Initial draft received on 29 December 1980, and revised draft on 27 March 1981

I. Forward

At present, the research on attenuation of radiation in the 8-13 micron window region in the atmosphere is stressed. One of the reasons is that the window region is situated in the vicinity of the blackbody radiation function of the Earth's temperature; the exchange of energy between the Earth and the atmosphere mainly proceeds in this spectral region. The other reason is that the astronautical remote sensing and sounding of the earth environment can be realized. As revealed in the theory of light scattering and absorption in a turbid medium and analysis of the aeronautical and astronautical remote sensing data, besides the inherent gas components, aerosol particles of various sizes floating in the atmosphere have a significant effect on the atmospheric optical characteristics in this infrared window region. However, it is relatively difficult to accurately estimate contributions of radiation attenuation in the 8-13 micron window region by aerosol particles; this is mainly because of the complexity of the physical and optical characteristics of the aerosols. The paper attempts

to estimate the effect of radiation transmission in the 8-13 micron window region by atmospheric aerosol particles through theoretical calculations.

II. Concentration and Spectral Distribution of Atmospheric Aerosols

Studies on concentration and spectral distribution of aerosol particles are the most important in estimating the relative contribution of radiation transmission by aerosols. In the atmosphere, the physical structure and optical characteristics of aerosol particles vary continuously with respect to time and space. At the same time, the particle components are also quite different with different origins and differences in the atmospheric environment. Since the atmosphere is a mixed system of various gases and aerosol particles, the physical characteristics of the aerosol particles, to a considerable extent, are affected by the atmospheric conditions and the geographical environment.

In order to obtain data on aerosol characteristics in the atmosphere, on site observations were conducted in a non-industrial contamination area, Xianghe (approximately 70 kilometers to the southeast of Beijing), by electro-optical methods on concentration and spectral distribution of aerosol particles. Notwithstanding the complex evolution process in the physical structure of aerosols, it can still be considered that the concentration of a certain particle and the particle spectrum of a certain type are the revelation, to a certain degree, of physical characteristics of a certain gas mass. Thus, the author and his colleagues divide the observation results into two major categories, according to climate visibility: clean atmosphere (visibility V greater than 30 kilometers) and turbid atmosphere (visibility V less than 15 kilometers). As revealed by the measurement results, for a non-industrial contamination plain area like Xianghe, in most cases (above 80 percent) of clean atmosphere, the particle concentration (range of particle diameter is 0.3 to 10 microns) is in the range of 25 to 100 particles per cubic centimeter. Figure 1 presents the average particle spectrum of 282 sets of measurement data of the particle spectrum under different atmospheric conditions. It is apparent that the entire particle spectrum clearly moves toward the large particle side in a turbid

atmosphere. In a clean atmosphere, on the average the radius of about 80 percent of the particles is less than 0.2 micron while only about 20 percent of the particles maintains a radius greater than 0.2 micron. Of the comparable figures in a turbid atmosphere, the corresponding values are, respectively, 43 and 57 percent. As revealed by measurement results, the quantity of large particles in the atmosphere rapidly decreases with increase in dimensions; however, the variation of the particle spectrum is not smooth. One or more secondary high values often appear in the distribution curve of the particle spectrum. This phenomenon is also apparent in the average data given in Fig. 1. In addition, the analysis of observation results reveals that the relative variation in concentration is not consistent with different sizes of particles under different atmospheric conditions. The maximum relative variation amplitude of the particle spectrum is in these particles within the range of radius between 0.2 and 1.0 micron; the relative variation of particles (0.4 micron in radius) can be tenfold different in clean and turbid atmosphere. This is very important in estimating radiation attenaution of the infrared window region of aerosol particles in different atmospheric conditions.

III. Radiation Attenuation in the 8-13 Micron Window Region by Aerosols

(A) Calculation method

The radiation attenuation caused by aerosol particles is calculated according to the Mie theory. In order to make corresponding theoretical explanations, two points should be raised here. The first point is that the relationship between the optical characteristics and physical characteristic quantity of aerosol particles is relatively complex. The attenuation to electromagnetic radiation by the particles is not simply determined by the geometric cross section of the particles, but by the relative dimension X of the particles:

$$X = 2\pi r/\lambda \qquad (1)$$

Here λ is the wavelength of the electromagnetic radiation and r is the particle radius. The second point is that the absorption effects of some aerosol particles have importance in the radiation attenuation of the 8 to 13 micron window region.

In the Mie theory, the fundamental assumption is that aerosols are spherically uniform particles. Here, at wavelength λ the coefficient of volume attenuation $C(\lambda)$ of aerosol particles is:

$$C(\lambda) = 10^{-3}\pi \int N(r)r^2 \cdot Q[r, \lambda, m(\lambda)]dr \qquad (2)$$

Here, N(r) is the spectral distribution of aerosol particles: $Q[r, \lambda, m(\lambda)]$ is the total attenuation factor of the particles, and $m(\lambda) = n(\lambda) - in'(\lambda)$ is the multiple refractive index of the particles. In calculation, the value of $m(\lambda)$ is taken from manuscript [1], and Q is calculated from the following approximate formula [2].

$$\begin{aligned} Q = {} & 2 - 4e^{-\rho\tan\beta} \cdot \left(\frac{\cos\beta}{\rho}\right) \sin(\rho - \beta) \\ & - 4e^{-\rho\tan\beta} \cdot \left(\frac{\cos\beta}{\rho}\right)^2 \cos(\rho - 2\beta) \\ & + 4\left(\frac{\cos\beta}{\rho}\right)^2 \cos 2\beta. \end{aligned} \qquad (3)$$

In the formula, $\rho = \frac{4\pi r}{\lambda}(n-1)$, $\tan\beta = \frac{n'}{n-1}$.

Calculations proceed to spectral distribution of two types of aerosol (clean and turbid, referring to Fig. 1) and two types of particles (water drops, quartz particles and the equivalent particles of $m(\lambda) = 1.54$). Figure 2 presents results of all six sets of data.

(B) Discussion of results

As revealed from the calculated results, there are considerably different attenuation effects produced by radiation in the range of 8-13 microns by

particles of different refractive indexes. The attenuation function of particles (m=1.54) in this window region rapidly decreases with increase in wavelength (curves 5 and 6 in Fig. 2) because this kind of attenuation is caused by scattering of particles. When the aerosol particles are enveloped by other particles of the water layer, the attenuation effect is not only determined by particle scattering, but also is closely related to the absorption characteristics of these particles. As revealed by curves 1 and 2 in Fig. 2, the attenuation caused by these particles is the smallest in the 10-11 micron wave band; the volume attenuation coefficient C is smaller than $1x10^{-3}$ per kilometer. In the long wave end of this window region, the value of C significantly increases with increase in wavelength. This apparently is caused by increasing absorption effects of liquid-state water. As to quartz particles, the relationship between attenuation characteristics and wavelength is even more apparent (curves 3 and 4 in Fig. 2). In particular, in the situation of a turbid atmosphere, the variation amplitude of the volume attenuation coefficient may have a range from $5x10^{-3}$ to $65x10^{-3}$ per kilometer. It is clear that in precisely estimating the effect of 8-13 micron remote sensing and sounding on aerosols, not only are the data of concentration and spectral distribution of aerosol particles required, but also reliable data on the related particle components are indispensable. For example, more intensive absorption has been discovered [3, 4] in the vicinity of 9 and 11 microns due to particles of silicates, alumina, carbonates and sulfates.

In different atmospheric conditions, the relative contributions of aerosol particles to radiation attenuation in the 8-13 micron window region is apparently not the same. As revealed by the calculation results, compared with a clean atmosphere, the attenuation coefficients are apparently increased (generally, increasing by 2-3 times or more), whatever the kind of particles under the situation of a turbid atmosphere.

For various types of astronautical remote sensing and sounding, it is often required to understand the radiation attenuation characteristics of aerosols in the entire atmosphere. For this reason, Fig. 3 gives the calculated attenuation coefficient σ_a in the 8-13 micron window region of

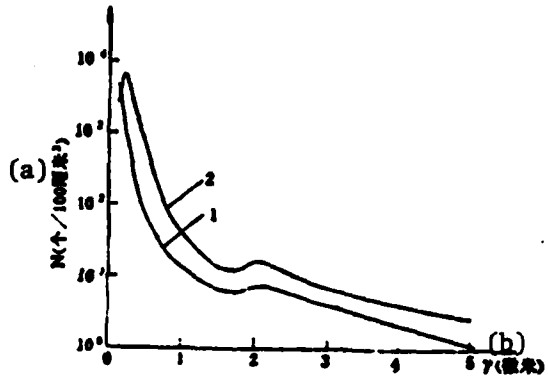

Fig. 1. Distribution of aerosol spectrum under different atmospheric conditions:
1. Clean atmosphere; 2. Turbid atmosphere.
Key: (a) Particles per 100 cubic centimeter; (b) Micron.

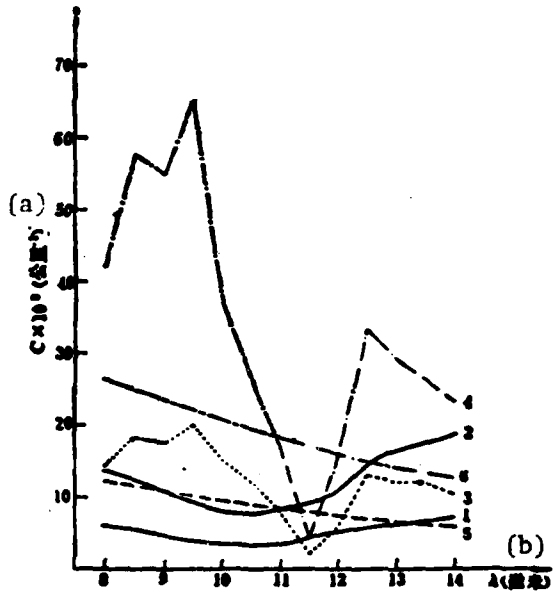

Fig. 2. Volume attenuation coefficient C of different types of aerosol particles (reflective index taken from [1]): 1. Liquid-state particles (clean atmosphere); 2. Liquid-state particles (turbid atmosphere); 3. Quartz particles (clean atmosphere); 4. Quartz particles (turbid atmosphere); 5. m=1.54 (clean atmosphere); 6. m=1.54 (turbid atmosphere).
Key: (a) Kilometer^{-1}; (b) Micron.

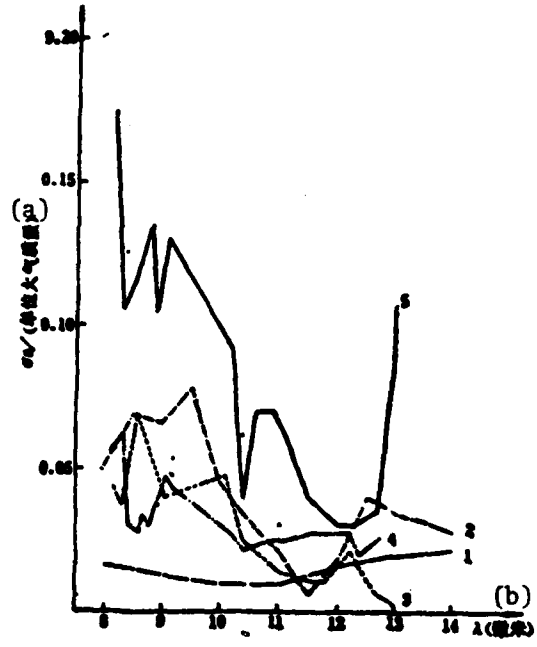

Fig. 3. Comparison between calculated and measured values of aerosol attenuation coefficient σ_a: 1. H_2O (calculated); 2. Quartz (calculated); 3. Clean atmosphere [6]; 4. Clean atmosphere [5]; 5. Contaminated atmosphere [7].
Key: (a) Unit atmospheric mass; (b) Micron.

aerosol particles in the entire layers of the atmosphere according to the measured particle spectrum. In the calculation, it is approximately considered that the particle spectrum does not vary with altitude and the altitude of aerosols as 1.2 kilometers. For comparison, Fig. 3 also presents some corresponding results obtained from the measured solar spectrum. The dotted lines 1 and 2 in Fig. 3 are the calculated results of liquid state water particles and quartz particles in a turbid atmosphere. The solid lines 3, 4 and 5 indicate, respectively, the measured results in different regions; lines 3 and 4 are plotted based on the non-industrial contamination area [5, 6] and line 5 indicates the observation results in the industrial contaminated area [7]. Notwithstanding different precisions of these data, Fig. 3 clearly indicates the radiation attenuation characteristic of aerosol particles in this window region. For a non-contaminated atmosphere (relatively clean) as indicated by lines 3 and 4, the radiation attenuation effects of aerosol particles in the 8-13 micron window region are close to the calculated line 2. This reveals that the components of aerosol particles in the atmosphere are relatively uniform. However, the situation is quite different in the industrial contaminated area, as the attenuation effects in this window region caused by particles are apparently increased (line 5 in Fig. 3). This indicates that attributes of aerosol particles in this area vary considerably compared to a non-contaminated area. According to research results of radiation characteristics of different aerosol particles, there is reason to believe that the atmospheric aerosols (in the contaminated urban area) are possibly composed of particles of coal smoke, asphalt and like substances because the radiation attenuation in the 8-13 micron window region caused by these particles is considerably greater than the ordinary dust and mineral dust [8].

Finally, it should be explained that the variation of the aerosol particle spectrum with altitude in the atmosphere is relatively complicated; it is relatively difficult to obtain the data for the particle spectrum at various altitudes in the atmosphere. In calculations of this paper, the measured ground particle spectrum is used and it is assuemd that the particle spectrum does not vary with altitude. In practice, the ground particle spectrum is considered the equivalent particle spectrum of the total layers

of the atmosphere; this processing method is generally acceptable for a relatively dry and stable atmosphere. However, in the situation of relatively intensive atmosphere layers or in the existence of a relatively intensive particle source (such as volcanic eruption), the particle spectrum at various altitudes of the atmosphere may have considerable difference with the corresponding ground particle spectrum. In these situaitons, double care should be taken in processing the particle spectrum of the total layers of the atmosphere.

IV. CONCLUSION

The analysis of the calculated results of radiation attenuation effects in the 8-13 micron window region by aerosol particles indicates the following points:

(A) The radiation attenuation of the infrared window region by atmospheric aerosols is mainly determined by the concentration, spectral distribution and components of the particles. Compared with a clean atmosphere, the attenuation coefficients of particles generally increase 2-3 times or even more in a turbid atmosphere.

(B) In a non-industrial-contamination area, the aerosol particles are mainly composed of various kinds of dust and certain organic and inorganic chemicals. For radiation attenuation in this window region of particles in the total atmosphere, it is assumed that in the case of quartz particles as aerosols, the calculated results are relatively close to the corresponding values as measured. The average value of the attenuation coefficient is approximately 0.04 per unit of the atmospheric mass in the 8-13 micron window region.

(C) In the industrial contamination area, the radiation attenuation of aerosols in this window region is apparently increased. However, due to the relatively complex constituents of particles, the calculations are relatively difficult. In addition, in different contaminated areas, possibly the attenuation effects of infrared radiation by particles have relatively greater differences.

Attenuation by different kinds of aerosols has been calculated on the basis of size distribution measured in the real atmosphere and compared with the results measured by solar spectrum. The physical characters of the aerosols and radiation attenuation under different atmospheric conditions have also been analysed. The results show that attenuation by atmospheric aerosols in the 8—13 μ window depends not only on the concentration and the size distribution but also on the chemical composition of the aerosols. The attenuation by polluted atmosphere is obviously different from that by the clean atmosphere.

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